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Analysis of Minimum Efficiency Performance Standards for Residential General Service Lighting in Chile

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1 Overview

Minimum Efficiency Performance Standards (MEPS) have been chosen as part of Chile's national energy efficiency action plan. As a first MEPS, the Ministry of Energy has decided to focus on a regulation for lighting that would ban the sale of inefficient bulbs, effectively phasing out the use of incandescent lamps. Following major economies such as the US (EISA, 2007) , the EU (Ecodesign, 2009) and Australia (AS/NZS, 2008) who planned a phase out based on minimum efficacy requirements, the Ministry of Energy has undertaken the impact analysis of a MEPS on the residential lighting sector.

Fundacion Chile (FC) and Lawrence Berkeley National Laboratory (LBNL) collaborated with the Ministry of Energy and the National Energy Efficiency Program (Programa Pais de Eficiencia Energetica, or PPEE) in order to produce a techno-economic analysis of this future policy measure. LBNL has developed for CLASP (CLASP, 2007) a spreadsheet tool called the Policy Analysis Modeling System (PAMS) that allows for evaluation of costs and benefits at the consumer level but also a wide range of impacts at the national level, such as energy savings, net present value of savings, greenhouse gas (CO_2) emission reductions and avoided capacity generation due to a specific policy. Because historically Chile has followed European schemes in energy efficiency programs (test procedures, labelling program definitions), we take the Ecodesign commission regulation No 244/2009 as a starting point when defining our phase out program, which means a tiered phase out based on minimum efficacy per lumen category.

The following data were collected in order to perform the techno-economic analysis:

- Retail prices, efficiency and wattage category in the current market
- Usage data (hours of lamp use per day)
- Stock data, penetration of efficient lamps in the market

Using these data, PAMS calculates the costs and benefits of efficiency standards from two distinct but related perspectives:

- The Life-Cycle Cost (LCC) calculation examines costs and benefits from the perspective of the individual household.
- The National Perspective projects the total national costs and benefits including both financial benefits, and energy savings and environmental benefits. The national perspective calculations are called the National Energy Savings (NES) and the Net Present Value (NPV) calculations. PAMS also calculate total emission mitigation and avoided generation capacity.

This paper describes the data and methodology used in PAMS and presents the results of the proposed phase out of incandescent bulbs in Chile.

2 Life Cycle Cost and Payback Period

2.1. Definition and Methodology:

The calculation of Life Cycle Cost is an effective way of assessing the impacts on standards and labelling programs to the individual consumer. There are usually several possible technologies that deliver the same utility to the user while consuming less energy: here incandescent lights (IL) are evaluated against compact fluorescent lamps (CFLs).
Implementation of efficient technologies generally results in added production costs, which are passed down to the consumer in the form of higher retail prices. The Life Cycle Cost calculation analyzes the trade-off between these increased first costs, and subsequent savings in the form of lowered utility bills. The Life Cycle Cost analysis takes into account the preference for immediate over deferred gains by scaling future energy cost savings by an appropriate discount factor.

Life-Cycle Cost is given by

$$LCC = EC + \sum_{n=1}^{L} \frac{OC}{(1+DR)^n}$$

, where *EC* is equipment cost (retail price), *n* is the year of operation and *OC* is the annual operating cost. Operating cost is summed over each year of the lifetime of the appliance *L*. Operating cost is calculated by multiplying the Unit Energy Cost (UEC, in kWh) by the price of energy (*P*, in dollars per kWh) as follows:

$$OC = UEC \times P$$

Unit Energy Consumption and energy price are assumed constant from year to year. The fact that future costs are less important to consumers than near-term costs is taken into account by dividing future operating costs by a *discount factor* $(1+DR)^n$, where *DR* is the discount rate.

The payback period (PBP) refers to the time it takes a consumer to recover, through lower operating costs, the assumed higher purchase cost of more energy efficient products. Numerically, the PBP is the ratio of the increase in purchase cost (from a less to a more efficient design) to the decrease in annual average operating cost. This calculation does not use a discount rate to discount future operating costs.
The equation for determining PBP is:

$$PBP = \frac{\Delta EC}{\Delta OC}$$

2.2. Input Data:

The following table summarizes the input data used to calculate the life cycle cost.

Table 1 - Summary of inputs into the life cycle cost analysis

Input	Product	Average Value	Source
Baseline retail price *EC*	Incandescent	0.70 [1]$	Fundacion Chile
	CFL	6.48$	Fundacion Chile
Average *UEC*	Incandescent	97.3kWh	Market Weighted Average
	CFL	23.6kWh	
Usage	All	3.8hrs per day	Household Survey Market Weighted Average
Lifetime *L*	Incandescent	1 Year	Based on 1000hrs lifetime
	CFL	5 Years	Based on 6600 hrs lifetime
Consumer Discount Rate *DR*		10%	PPEE
Electricity Price *P*		0.18$/kWh	Chilectra

2.3. Results

In our scenario we assume that 100W incandescent will get replaced by 20W, 75W and 60W by 15W and 40W and 25W by 10W based on lumen outputs. Because of the shorted lifetime of the incandescent bulbs, the LCC is based on the lifetime of a CFL, which means that the LCC takes into account that in every year of the CFL lifetime the consumer buys a new incandescent bulb. This cost is included in the operating costs and is discounted appropriately.

The following table presents the results of our life cycle cost:

Table 2 - Life Cycle Cost results by Lamp Type and Power Category

IL Category	LCC Base Case	CFL Category	LCC Policy Case	PBP (years)
100W	$90	20W	$26	0.41
75W	$68	15W	$19	0.37
60W	$64	15W	$20	0.34
40W	$44	10W	$16	0.63
25W	$28	10W	$17	1.23

[1] A conversion rate of 559 Chilean Pesos for 1 US$ was used (average rate in 2009 from x-rate.com)

In every configuration, the life cycle cost of an incandescent is far more important than the CFL life cycle cost. The consumer experiences a net financial benefit in buying a CFL instead of an incandescent bulb. The period of return on investment is also very low, less than a year in most cases, which means that even if the CFL had a one year lifetime like an incandescent it would still be cost effective. Such a high ratio of cost effectiveness is due to relatively high electricity tariffs in Chile.

3. National Stock and Sales Forecast

In addition to the financial impacts on individual consumers, policy makers also consider the magnitude of efficiency impacts to the nation as a whole, which is where the sales and stock of lights are taken into account.
PAMS calculates in every year the number of bulbs in the country in the business as usual case and in the efficiency case, and keeps track of the fraction of CFLs vs ILs in the stock.

3.1 <u>Base Case Stock</u>

In the base case or business as usual case (BAU), historical data are used to determine the rate at which incandescent bulbs are replaced by CFLs. FC provided data from household surveys from 2005 and 2010, that shows an increased penetration of CFLs from 16% to 45%. In our forecast we have to take into account that some of this increased penetration is the results of PPEE's successful program of CFL give away. During this program, 1.5 million bulbs were installed in the 40% lowest income households in Chile. For this reason we only use 50% of the historical growth rate from 2005-2010. Also households tend to only replace the bulbs with the highest usage so we can expect that the growth will slow down. The following figure presents the base case scenario:

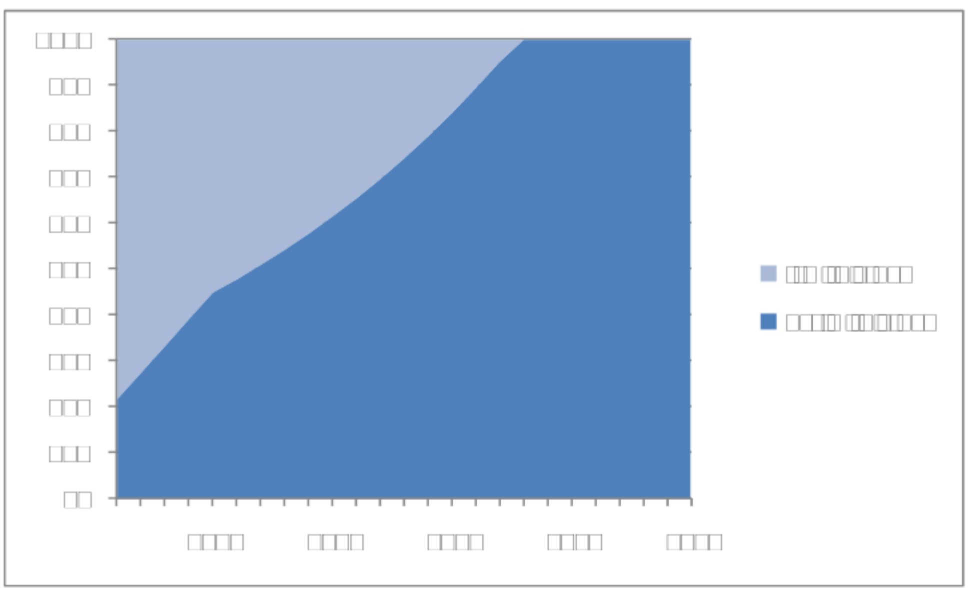
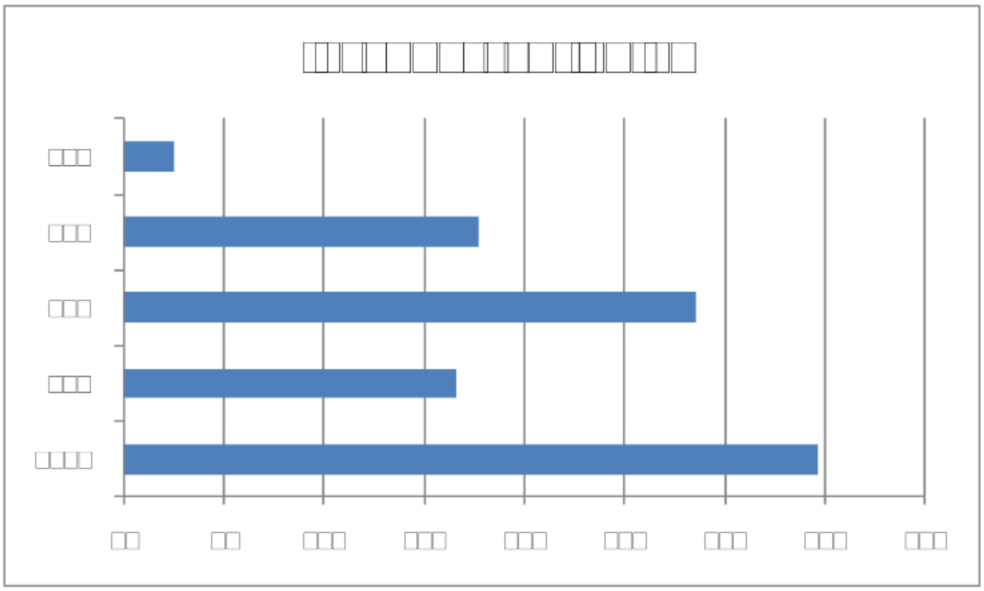


Figure 1 - Percentage of CFLs vs Incandescents in the Stock

We can see that in the base case, without any regulation, CFLs are phased out of the stock. This means that savings are to be gained in the next few years by accelerating the on-going phase out of incandescent bulbs. In our model, by 2023, the program doesn't have any impact anymore.

The two household surveys also show that the number of bulbs in use in the household hasn't changed significantly between 2005 and 2010. In order to be conservative, we assume that the number of bulbs per household is constant throughout the forecast period. This way, we probably underestimate the positive impact of the program.

Wattage market shares are based on the latest sales data (2009), and are assumed to be constant throughout the forecast period in the base case. In the policy case, the CFL market shares are slightly modified because of the conversion from IL into CFLs. The following graph represents the sales by power category:



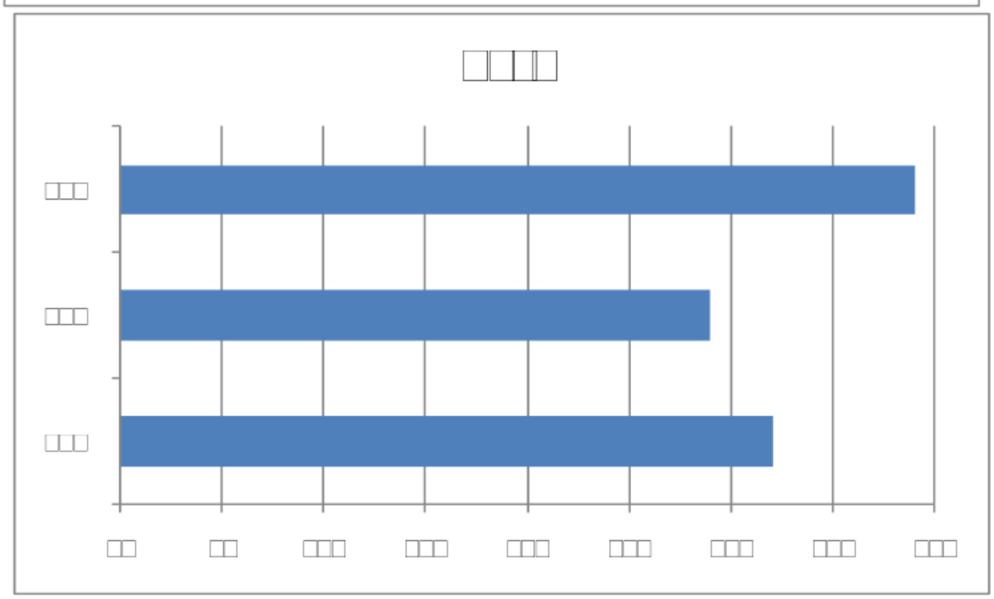


Figure 2 Sales Market Share by Power Category

3.2 Stock in the Efficiency Scenario

An efficiency scenario is created based the Ecodesign criteria defined in the Commission Regulation (EC) No 244/2009 and PPEE own schedule. We define a four step phase out based on minimum efficacy and lumen outputs. These criteria apply to every lamps sold in Chile after the MEPS enter into force.

The following table presents the reference schedule along with the criteria associated with each phase:

Table 3 Phase Out Schedule, Scope and Criteria

	Year	Lumen Category Impacted	Representative Power - Incandescent (W)	Maximum Power in Phase out Scenario (W)
Phase 1	2012	□>950 Lm	100	74
Phase 2	2013	□>725 Lm	75	55
Phase 3	2014	□>450 Lm	60	43
Phase 4	2015	All	40	28
Phase 4	2015	All	25	18

The following graph illustrates the impact of the program on the stock.

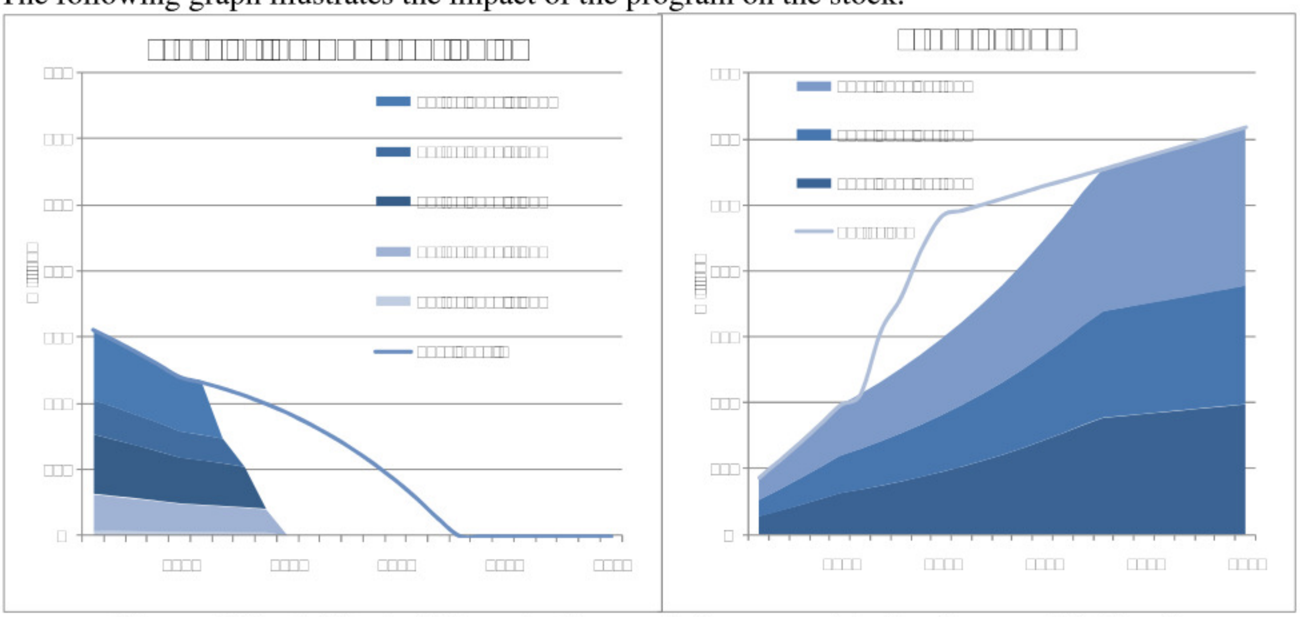


Figure 3 Stock Market Share by Power Category and in the Base and Policy Case

The area between the layer graph and the full line represents the number of bulbs that are displaced in the efficiency scenario. They are incandescent bulbs in the graph on the left and CFLs in the graph on the right.

4. National Impacts

4.1 Definitions and Methodology:

There are four major policy impacts that are calculated at the national level:

- Site/Source Energy Savings – In addition to energy saved in households, PAMS provides an estimate of the resulting savings in terms of site energy and input energy to power plants, including energy lost in transmission and distribution.
  In the base case and policy case, the consumption of the stock is calculated based on the number of bulbs of each type (incandescent, CFLs and by wattage) in every year.
  PAMS calculates National Energy Savings (NES) in each year by comparing the national energy consumption of the product under study in the base case to the policy case, according to

$$NES = NEC_{Base} - NEC_{Policy}$$

  The equation given above show energy savings calculate on a site basis. National utility and environmental impacts, however are driven by primary energy consumption, that is, total inputs of fossil fuel energy. Primary energy savings (PES) is calculated from site savings by taking into account the electricity generation fuel mix, and losses through transmission and distribution (T&D). The formula for PES is:

$$PES = \frac{NES}{1-TD} \cdot HR$$

  , where TD is the fraction of energy lost in transmission and distribution, and SSF is the heat rate.

- Emissions Reductions – Total reduction in CO_2 emissions in million tons (Mt) is calculated according to typical electricity generation fuel mix.
  Carbon dioxide emissions savings (CES) are calculated from energy savings, by applying carbon factors to site energy savings according to:

$$CES = \frac{NES}{1-TD} \cdot CF$$

- National Consumer Benefits – The Net Present Value (NPV) of the policy is calculated according to total incremental equipment costs paid, electricity bill dollars saved, and the national discount rate applied to program evaluation.
  National financial impacts in year y are the sum of equipment (first) costs and operating costs. National equipment cost (NEC) is equal to the retail price times the total number of sales. Sales are generated in PAMS based on the stock forecast. For incandescent bulbs, because their lifetime is 1 year, we assume that the sales are equal to the stock. For CFLs, PAMS takes into account the first purchase (FP) as the increase of CFLs in the stock from one year to another (due to increase in number of households, increased penetration of CFLs in the base case, or policy case) and replacements (REP) of CFLs which are retired from the stock, according to:

$$Sales(y) = FP(y) + REP(y)$$

$$\text{Where } REP(y) = \sum_{age=1}^{L} Stock(y-1, age) \cdot P_R(age)$$

And the probability of retirement P_R varies with the age of the CFL and is based on a normal distribution illustrated in the following graph:

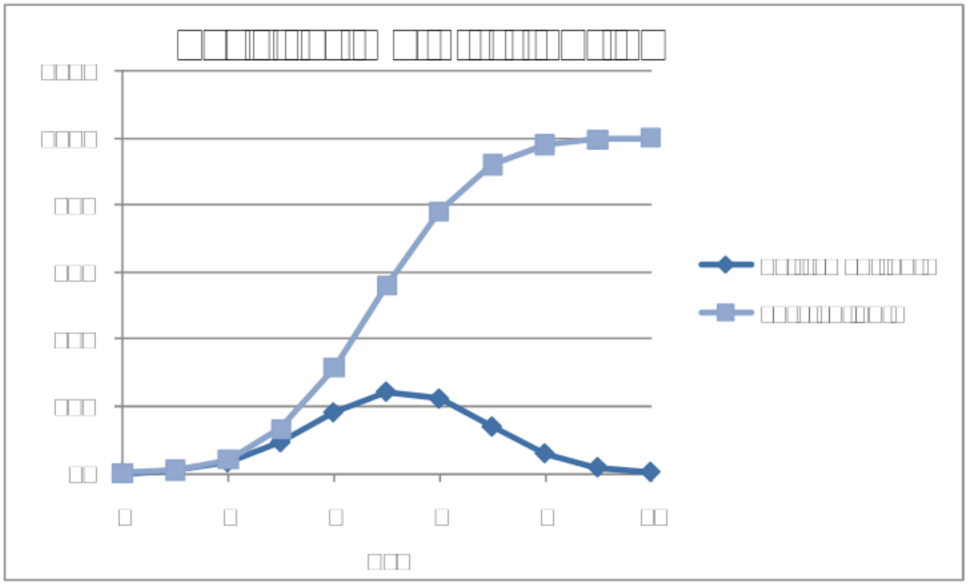


Figure 4 Retirement and Survival Function for CFLs

The net savings in each year arises from the difference in first and operating costs in the standards versus the base case, ΔNEC and ΔOC. Net Present Value of the policy option is then defined as the sum over a particular forecast period of the net national savings in each year, multiplied by the appropriate national policy discount rate:

$$NPV = \sum_{y} (\Delta NOC(y) - \Delta NEC(y) * Sales(y)) * (1 + DR_N)^{-(y-y_0)}$$

Where the national equipment cost is given by

$$NEC = EC \times Sales(y)$$

Finally. National Operating Cost (NOC) is the total (site) energy consumption times the energy price.

$$NOC = NEC(y) \times P$$

- Avoided Generation Capacity – The avoided capacity is calculated in the year where the savings are the most important and represent the instant power saved at the national level during peak load. The site savings are converted into generated electricity by using the transmission and distribution loss percentage, *TD*. Then the produced energy is converted into peak demand reduction according to:

$$Q = \frac{Max(NES)}{1 - TD} \cdot \frac{1}{8760} \cdot \frac{PK}{U \cdot K}$$

In this equation, 8760 is the number of hours in a year. PK is the peak coincidence factor, that is, the percentage of lighting energy use that occurs during peak hours. Assuming the peak period is between 6 and 12 PM, and lighting is used exclusively during this time, PK is 100%. The use factor U is the percentage of time that lighting is used, which is 6 hours per day, or 25%. K is the average load capacity of the plants.

4.2 <u>Input Summary:</u>

The following table summarises the inputs used in the national impact analysis.

Table 4 Summary of Inputs for National Impact Analysis

Input	Average Value	Source
Generation Factor *HR*	2.0	PPEE
T&D Loss Factor *TD*	8.0%	PPEE
CO2 emissions *CE*	0.480kg/kWh	PPEE
Plant Capacity Factor *K*	80.0%	PPEE
Peak Coincidence Factor *PK*	100.0%	Assumption
Usage factor *U*	25%	Assumes lights are used on and off between 6pm and midnight
Discount Rate DR_N	6%	PPEE

4.3 <u>Results</u>

As shown in the following graph, PAMS calculates in every year the incremental equipment cost and energy savings from the program. We can see that the consumer experiences net savings as early as the first year of the program. This is due to the very low payback period that is less than a year for most of the bulbs. We can see that the peak of the benefit of the program occurs in 2015, and that the program only has an impact before 2023. This is due to our assumption of a phase out of incandescent in absence of a program by 2023.

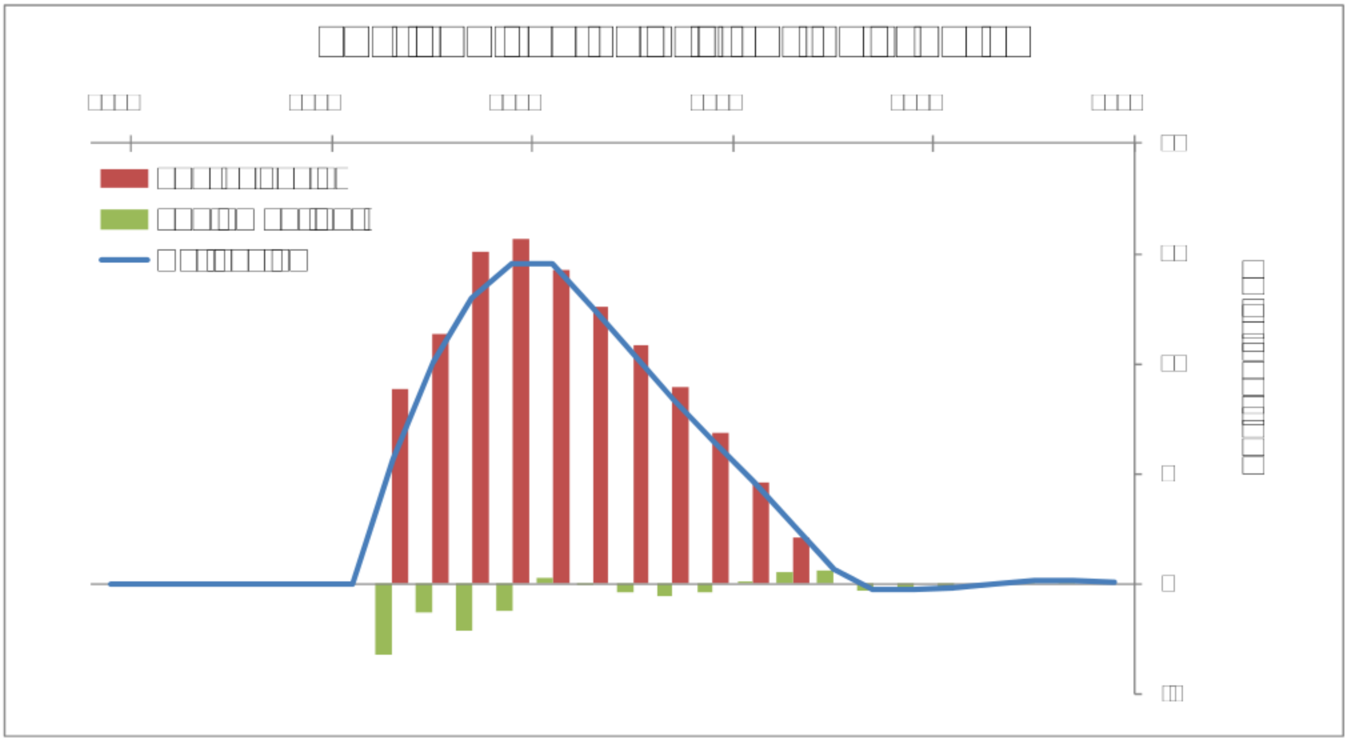


Figure 5 Annual Cost and Savings of Lighting Program

The following tables present the cumulative energy savings, CO_2 emissions savings and avoided plant capacity.

Table 5 National Energy and CO_2 Emission Savings and avoided Capacity from Policy

NES (GWh)	Reference Scenario
through 2020	9,408
through 2030	10,034
PES (Mtoe)	
through 2020	1.82
through 2030	1.94
CO2 emissions (Mt) through 2030	5.24
Avoided Generation (MW)	872

These numbers have to be put in perspective in the Chilean context. According to IEA, the annual electricity consumption in the residential sector in Chile was 8,745 GWh in 2008, so the site electricity savings by 2020 are a bit higher than one year equivalent of electricity consumption in the entire residential sector.

Table 6 presents the cumulative discounted economic impacts.
Table 6 National Economic Impact from Policy

	Economic Impacts (Billion 2009$)
Total Electricity Cost Savings through 2030	1.270
Total Incremental Equipment Cost through 2030	0.106
NPV (2010-2030)	1.164

The NPV calculation shows that there is a benefit cost ratio of 12:1 between the initial investment and the discounted savings experienced over the lifetime of the bulb. For each dollars invested in a CFL, the consumer will get 12$ back though its electricity bill savings. Considering the population of Chile in 2010 as a reference, each inhabitant will receive a 68 $ benefit over the entire program.

5.Sensitivity Analysis

This section presents the national impact analysis under different scenarios. First, different schedules of phase out are studied. A slow phase out, with a phase every two years, and a rapid phase out with a phase every six months. Then a second sensitivity is created around the penetration of CFLs in the stock. A first scenario assumes frozen efficiency (penetration of CFLs are maintained constant), while a second BAU scenario is based on the 2005-2010 growth rate. Also we explore the effect of the electricity price going up at a 2% annual growth rate.
The following table presents the results of the sensitivity analysis on the national impact analysis.

Table 7 National Impacts under different scenarios

	Reference Case (Intermediate Pace, Intermediate Eff Improvement)	Phase out Pace		Efficiency Improvement in BAU	
		Slow	Rapid	Frozen	High
Cumulative NES (GWh)					
through 2020	9,408	7,938	10,233	18,154	5,199
through 2030	10,034	8,564	10,859	44,692	5,199
NPV (Billion $)					
Constant Electricity Price	1.16	0.99	1.27	3.78	0.65
High growth Electricity Price	1.36	1.15	1.48	4.92	0.74
CO2 emissions (Mt) through 2030	5.24	4.47	5.67	23.32	2.71
Avoided Generation (MW)	872	705	938	1763	624

This sensitivity analysis gives an idea of the margin of uncertainty around the number presented for the reference scenario. We can see that the NPV results are not too sensitive to electricity price growth, which is due to the fact that savings occur in the next few years after the program is launched, so the electricity saved through the program doesn't reach a high price. A major influencing factor is the assumption around the number of CFLs that would enter the stock by 2020, or by 2030… We believe that the reference scenario represents a good compromise. For example, in the preparatory study for Ecodesign, it was assumed that 30% of incandescent bulbs would remain in the stock by 2020 vs 16% in our reference scenario here. Even though the contexts are different, this gives us an indication that we are in the right order of magnitude. The pace of the schedule is more of a political issue than a modelling issue, so these results are presented as indicative of how the savings would be impacted if the ministry of energy should decide to modify the schedule.

6.Conclusions

Thanks to a cost benefit analysis, this proposed phase out of incandescent shows its large benefits compared to the incremental cost both at the consumer level and the national level. If implemented as assumed in PAMS, the program will save over 1 billion US$ over the next 20 years, avoid more than 10 TWh of electricity and 5 Mt of CO_2 emissions. PAMS shows that most of the savings will occur in the next years will penetration of CFLs is still low, savings will peak in 2015 in Chile if the program starts in 2012. The Ministry of Energy and PPEE are still working on impacts on low income families in Chile and programs to help them cope with the initial incremental cost of buying a CFL.

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